eRD106 (Forward EMCal) R&D Project for Forward EM Calorimeter at Hadron Endcap
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- We propose to build a full scale forward EMCal and HCal system. This R&D plan covers the Forward EMCal component which consists of 64 superblocks or modules. With the construction and beam testing of the calorimeter system, we expect to address all technical, performance and cost questions related to the final design of the Forward Hadron Endcap Calorimeter System (EMCal + HCal) for proposed EIC detectors and meet the requirements of forward calorimeter system specified in the EIC Yellow Report.
- We expect that the R&D team will develop the construction techniques and facilities that can be carried over to the EIC detector construction phase. Such development in both technological know-how and human resources will be valuable step towards the next phase of EIC detector development beyond FY2024.

We will deploy the W-powder/Scintillating Fiber (WScFi) technology for the EMCal block. The WScFi EMCal technology was pioneered by the UCLA group and it was the first project funded by generic EIC R&D program (eRD1). This technology was adopted and further developed by the sPHENIX collaboration for barrel EMCal, which is expected to complete its construction near the end of 2021. The WSiFi construction technology is well suited for Universities and sPHENIX has major production factories in operation in the US and China. Our R&D plan will address these outstanding technical questions further improving the performance of the detector for EIC applications:

1. Uniformity of light collection with compact SiPM readout
2. Efficiency of light collection. Both the STAR UCLA team beam test run in 2014 and the sPHENIX test run data indicated that there are rooms for improvement in light collection efficiency. We estimate to achieve an improvement of factor ~ 2.5 to comfortably meet requirements on minimum energy detection as specified in the YR.

The UCLA group continued R&D effort in 2015/2016 to address the first question. We tried different method to compensate for hot spots including compensation filters between fibers and light guides (help with uniformity and further decrease efficiency of light collection), or compensated mirror at the far end of the fibers (opposite to light guides) which turned out challenging and problematic. The final method tried at that time was to introduce a controlled non-uniformities with pre-bunching of fibers – the main idea is to make light pass for fibers at the edge of towers somewhat similar to the light pass from fibers at the center of towers. Figure 1 shows scans with UV source exiting fibers at far end. This method significantly improved the light collection uniformity. Non-uniformity was reduced by a factor of 4.5 compare to earlier prototypes (or sPHENIX current version). We will be using this construction technique to build 64 modules of 256 channels EMCal prototype needed for test run. This technique has not been used for any experiment yet.

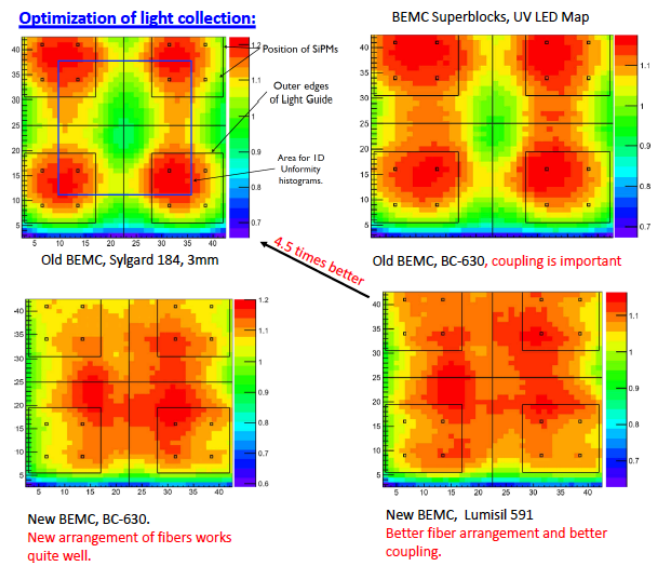

Figure 1. Response uniformity maps. Figure from EIC Generic R&D Project eRD1 2015 report.

Additional improvements of non-uniformities will come from using larger area SiPMs. In previous test runs and measurements we used 3 mm x 3 mm SiPMs. For EIC EMCal we plan to use 6 mm x 6 mm SiPMs. The primary reason is to enhance the light collection efficiency. With increased area of photo-sensors by a factor of 4, we should be able to collect more light. We should be able to achieve the targeted number 1000 p.e./GeV, compared to present ~390 p.e./GeV. Optimization of light guides is also planned: instead of one trapezoidal light guide per tower we will have four sub-lightguides. For mass production we will attempt to produce with a single molded light guide for a super-sized EMCal block which will have 16 towers readout by 64 6 mm x 6mm SiPMs.

Another important question to be addressed is the mechanical/optical/electrical integration at the end of the EMCal superblock. This includes development of high density, low power consumption FEEs. Development will be carried out by G. Visser from IUCF. It will be a continuation of his development work for STAR FCS upgrade. The FEEs used for the STAR FCS EMCal are conceptually very close to what are required for EIC detectors. However, it is a challenging to increase the density by four times due to much higher granularity of EMCal for EIC and the need to integrate additional functionality like LED monitoring system at the FEE card. It is envisioned that one FEE card with 16 channels will be attached to the EMCal superblock. Exact mechanical coupling will be designed, prototyped and tested. A direct copy of the STAR FCS elegant scheme for coupling FEEs with SiPM boards will most likely not work for higher density EIC EMCal detector.

Readout of the EIC EMCal system will be adapted from the STAR FCS readout system (DEP). We'll need to make new trigger/clock distribution system for the test run. We plan to upgrade DEP for full streaming readout mode. It is envisioned that full streaming readout mode will be available sometime in summer 2022. In what mode we use DAQ at FNAL is TBD. A triggered system like that at STAR is a straight forward option at least for the first test run when we will have lots of new detectors to test.

Milestones for FY22:

- Production of 64 + 2 spare EMCal superblocks by Chinese Consortium
- Design of readout (FEE/SiPM boards)
- Integration within EMCal superblock
- Optimization of light guides.

Plan for FY23.

- Production of readout electronics.
- Production of SiPM boards
- Test Run at FNAL

Manpower: Chinese EIC EMCal Consortium (Fudan, Shandong University, Tsinghua and South China Normal University) + UCLA +IUCF +BNL

US manpower: Postdocs/grad students and senior personnel funded from UCOP MRPI for EIC (2012-2024) and US DOE and NSF base grants. G. Visser (IUCF) supported from R&D funds.

Funding Profile:
FY22 – EMCal Block Production $68k, IUCF -$46k
FY23 – Light Guide Production $20k, UCLA - $34.7k, IUCF -$12k
FY24 – Possibly Second Test Run, UCLA - $18k

Material	Quantity per unit	Quantity Total	Price per unit	Price total	Contingency ~30%
Sc. Fibers	3120 x 0.2m	40000m	$0.5/m	$20k	$26k
W Powder	4.6 kg	300 kg	$45/kg	$13.5k	$17.6K
Meshes	6	384		$1.5k	$2k
Epoxy	0.5 kg	32 kg	$100	$3200	$4.2k
Supplies	Shafts/tubing			$2k	$2k
Molding Forms	1	10	$300	$3k	$4k
Machining				$6k	$8.2k
Shipping	2			$4k	$4k
EMCal Block Production					$68k

SiPMs	16 6 mm x 6 mm	1024 + 100 spares	$16	$17,984	$23k
EMCal FEEs	1	64 +6	$150	$10.5k	$13.7k
Light Guides	1 x 4 iterations	64 x 4	$50	$3200	$6.4k
Light Guides Molding form	2 iterations				$20k
Cables/patch panels etc.	1	64 + spares	$100	$6.4k	$8.3k
SiPM Boards	4	256 +10	$20	$5.3k	$5.3k
DEP/Crates System	1	8 boards	Same as for HCAl		
LV Power supplies		2		contributed	UCLA
DAQ PC		1	Same as for HCAl		
Gerard's Time	360 h/ year		$100/hour	$36k	$36k

Travel	Test Run FNAL (HCAL Budget)		$15k	$15k
Shipping to FNAL			$3k	$3k

Total for EMCal: $198.7k